CANADIAN
AQUACULTURE
SYSTEMS
BIOENGINEERING TECHNOLOGIES & BUSINESS MANAGEMENT SERVICES

AQUACULTURE WASTEWATER TREATMENT:

WASTEWATER CHARACTERIZATION AND DEVELOPMENT OF APPROPRIATE TREATMENT TECHNOLOGIES FOR THE NEW BRUNSWICK SMOLT PRODUCTION INDUSTRY

WORKING PAPER

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EXECUTIVE SUMMARY

The environmental impact of intensive fish culture has long been discussed, however, implementation of economically feasible and effective technologies for effluent treatment remains minimal on an industry-wide scale. The design of treatment units requires a fundamental understanding of all aspects of fish culture and wastewater engineering. This extensive field study examines commercial fish production practices, culture facilities design, suspended solids settling behaviour, and critical design parameters of existing effluent treatment operations, in an effort to identify those factors which most significantly affect effluent quality and management in commercial culture of Atlantic Salmon smolts in the province of New Brunswick.

Sedimentation practices (i.e. gravity settling) tend to be most widely applicable in intensive salmonid aquaculture; they require no energy input or specialized operating skills, are relatively inexpensive to install and operate, and can be easily incorporated into both new and existing facilities. A detailed overview of sedimentation design (including a design example) for intensive smolt culture operations is included.

ACKNOWLEDGEMENTS

This working paper is a summary of the findings of a larger report which was conducted for the Province of New Brunswick in 1989. The complete report is on file with the Department of the Environment in Fredericton, N.B.

The investigation was developed and implemented through the co-operative efforts of the New Brunswick Department of Fisheries and Aquaculture, the Department of the Environment, and the private and government aquaculturists throughout New Brunswick who permitted us to visit their operations to obtain the necessary water quality samples and data.

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1.0 INTRODUCTION

For more than 20 years, the potential pollution problems associated with fish farming have been recognized. Aquacultural wastewater treatment is no longer viewed as an option in fish farming; it is considered to be necessary for the protection of the receiving water course and the assurance that water quality objectives are attained.

In aquaculture, there is a saying: "Fish don't pollute, but feed does!" As with all animals, feed is only partially utilized by the fish; the remainder is discarded into the water as soluble metabolic by-products and solid waste. Consequently, intensive culture practices can lead to substantial deterioration of water quality.

Fish fecal matter, residual feed, and soluble metabolic products comprise the greatest pollution problems. Since most salmonid aquaculture facilities are located on sites containing high-quality water resources, the solid waste component presents a serious pollution problem, especially when farm effluents are discharged to sensitive cold-water receiving bodies.

Aquaculture-related pollution problems manifest themselves in various ways. The accumulation of solid matter on stream bottoms can be especially detrimental to aquatic environments. In fact, the Michigan DNR (1973) concluded that the total suspended solids load was the most significant problem caused by hatchery discharges. Since fecal and feed solids are predominantly organic matter, their oxidation depletes the dissolved oxygen concentration in the water and results in the release of dissolved nutrients. Moreover, these solid wastes support a diverse population of micro-organisms which also contribute to oxygen depletion, and which may be deleterious to other aquatic species. If left to accumulate to depths where bottom layers become anaerobic, noxious gases and other toxic compounds can form. Samuelsen et al. (1988) found that the gasses generated from fish farm sediment deposits consisted primarily of methane (70-90%), carbon dioxide (10-30%), and hydrogen sulphide (1-2%), all of which are toxic to fishes and other aquatic organisms.

The addition of phosphorus to aquatic habitats can present long-term pollution problems. The biologically available fraction of phosphorus (and to a lessor extent, nitrites and nitrates) in fish farm discharges contributes to the enhancement of primary productivity (i.e. increased populations of micro- and macro-algae), thereby promoting eutrophication of the receiving body of water. In fact, several studies throughout North America have identified phosphorus as a major pollutant in receiving streams below discharges from salmon fish culture operations as compared to sites immediately upstream of the farms.

The production of pollutants in salmonid aquaculture is directly related to the input of feed to the culture system and can be estimated using the accepted feed factors as described by Castledine (1986), and presented in Exhibit 1. Although effluent solids and nutrient concentrations in salmonid fish culture effluent are relatively dilute, long-term cumulative problems may develop in receiving waters due to the high volumetric flow rates required by salmonid fishes (Liao 1970a). Therefore, an effective means for reducing the solids content of the discharged effluent is necessary; however, the high volumetric flow rate, and the relatively dilute concentration of pollutants in the effluent, impose a unique constraint on effluent treatment. Consequently, treatment

technologies must be highly efficient, yet they must also be economically feasible to install and operate (Liao 1970b).

The uniqueness of most fish culture operations has meant that standard effluent treatment technologies have not been developed. Therefore, based upon an extensive field monitoring program, this paper presents standard design protocol for effluent treatment in New Brunswick smolt production operations.

Exhibit 1:
Accepted factors used to determine waste production from salmonid fish culture facilities based upon feed consumption.

Pollutant	Factor (x feed weight)[1]
Total Settleable & Suspended Solids	.300[2]
Settleable & Suspended Phosphorus	.0054
Dissolved Phosphorus	.0022
Total Phosphorus	.0076
Settleable & Suspended Nitrogen	.0064
Dissolved Nitrogen	.0317
Ammonia	.0383

Source: Castledine (1986)
[1] Factors will vary with changes in dietary efficiency. These factors assume dry feed (10% moisture) with an average digestibility of 80% and a Food Conversion Ratio = 1.2
[2] Westers (1989)

2.0 CHARACTERIZATION OF SMOLT PRODUCTION OPERATIONS

2.1 Production Characteristics

In September, 1989, 11 smolt production operations were visited throughout New Brunswick to investigate causative factors in the deterioration and treatment of fish farm waters. Industry average production, design, and untreated effluent water quality data are presented in Exhibit 2. Strong correlations exist between production parameters and effluent water quality. Most notably, increased intensity (i.e. carrying capacity) results in increased concentrations of nutrient pollutants (NH_3, TKN, TP and DP). Production area and total water flow are correlated with the effluent concentrations of total and dissolved phosphorus. This suggests that, as production area and total water flow increase, the effluent concentration of total and dissolved phosphorus decreases. Given a constant biomass of fish, both of these relationships suggest lower effluent concentrations of phosphorus due to dilution; the mass load of phosphorus, however, is undoubtedly unchanged. As expected, the retention time of water in the production system and the annual production level of a farm are not related to any aspect of effluent water quality. This suggests that all farms, big and small, have the potential to pollute receiving bodies of water.

Since solids settling behaviour is a principal factor in the design of treatment facilities, solids settling characteristics were measured at 9 smolt operations. Solids settling behaviour was observed to differ moderately among farms, however, most differences were not statistically significant. One farm (Farm 91) in particular, however, was found to differ significantly (F=11.3;

P<0.01) from the remainder of the group. The most notable difference in the defining characteristics about this farm is the use of a moist feed. This evidence *suggests* that moist feed may promote faster solids settling performance in New Brunswick smolt production. Among other farms, feed brand, feed type, and feeding method were explored as possible sources of between farm differences, however, no pattern was found. Settling curve equations are presented in the following chart for the N.B. smolt production industry as a whole and for Farm 91, which uses the moist diet. These equations are plotted as cumulative distribution design curves in Exhibit 3.

Group	Equation	F	P	n	r^2
N.B. Tanks	ln Cr = 0.47770 + 0.39804 ln Vo	320.7	P<0.001	101	0.764
N.B. Farm 91	ln Cr = 0.41223 + 0.88010 ln Vo	141.0	P<0.001	14	0.922

Exhibit 2:
Industry average production, design, and untreated effluent water quality data for New Brunswick salmonid smolt culture facilities. Water quality data is reported net of source water.

PROD'N & DESIGN VARIABLES	IND. AVG.	WATER QUALITY DATA	IND. AVG.
Ann. Prod'n (kg)	27619	Temperature (C)	14.4
Prod'n Area (m^2)	590.2	TKN (mg/L)	0.559
Prod'n Depth (m)	0.91	TAN (mg/L)	0.241
Standing Crop (kg)	6973	TP (mg/L)	0.109
Density (kg/m^3)	17.7	DP (mg/L)	0.052
Avg Fish Size (g)	27.5	TSS (mg/L)	2.790
Water Flow (Lps)	130.4		
Intensity (kg/Lps)	76.5		
Ret'n Time (min)	68.2		

2.2 Effluent Treatment Characteristics

In New Brunswick, nearly all operations utilize effluent treatment facilities. Settling ponds are the main treatment technology, however, one operation utilizes triangle filters. While most ponds have been designed with a substantial surface area for settling, poor inlet and outlet design, excessive depth, and the inability to clean solids from the bottom render them inefficient and/or ineffective in many applications. Design flaws generally stem from outdated criteria mandating a specific retention capacity within the pond. Moreover, point source inlet and outlet structures tend to be the norm, thereby exacerbating inefficiency. Furthermore, Westers (1989) indicates that, when solids are allowed to accumulate over long periods of time, settling ponds may function as nutrient sinks, accumulating solid nutrients only to later release them in dissolved form following decomposition and solubilization.

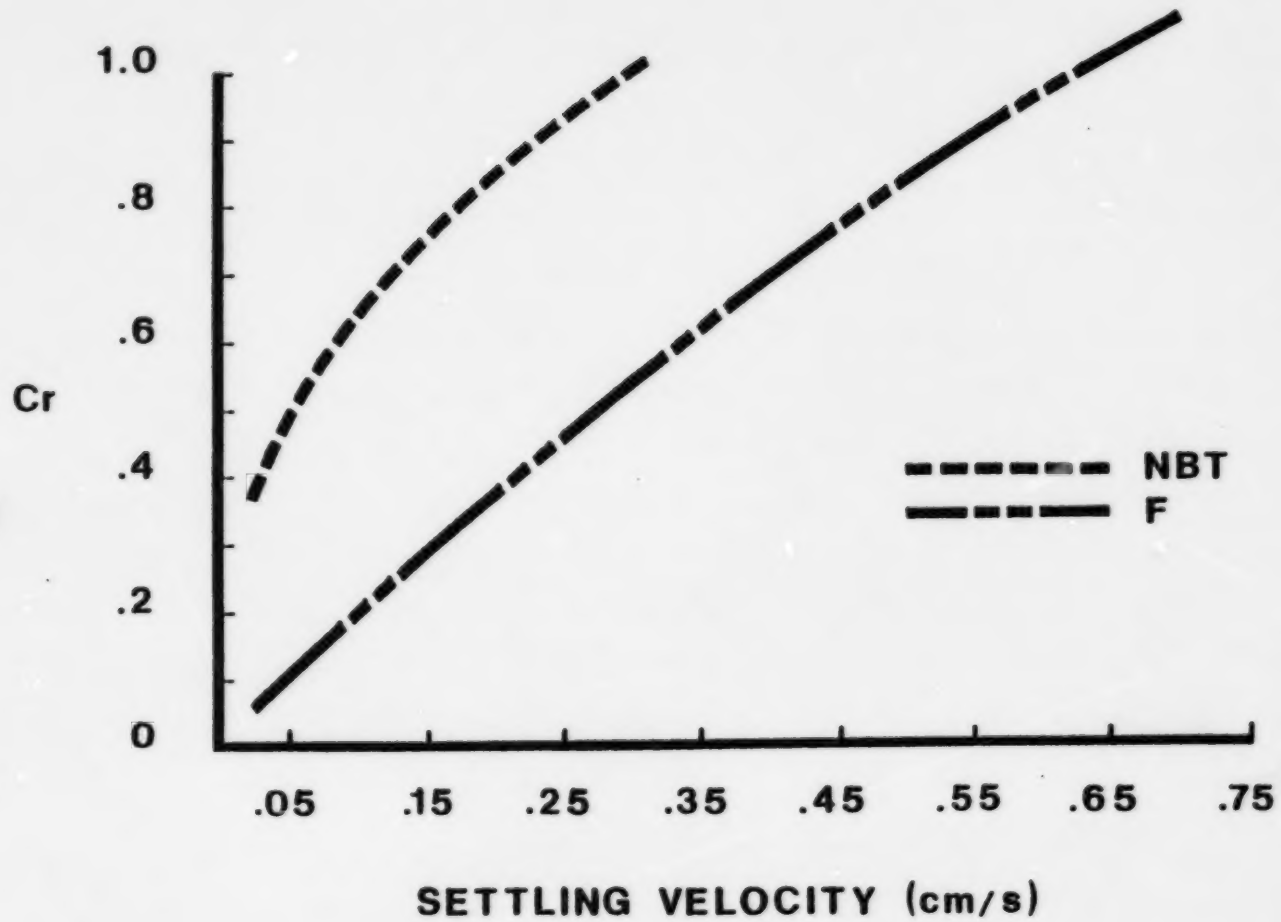


Exhibit 3:
Settling velocity profile for suspended solids from intensive salmonid smolt production facilities. NBT = New Brunswick circular tanks; F = Farm 91.

Data collected from N.B. aquaculture treatment facilities indicate that the removal efficiency of TSS from aquaculture effluents is poor, averaging only 22.2% in ponds. Similarly, removal of total phosphorus is also poor, averaging only 7.5% in ponds. Effluent concentrations of dissolved phosphorus are greater than influent concentrations, confirming that a portion of particulate phosphorus quickly becomes solubilized within the system. Data for all treatment units are presented in Appendix I.

Examination of the design and operating parameters for these effluent treatment facilities provides several explanations for the overall poor level of performance. In spite of average overflow rates within recommended guidelines (the greatest overflow rate in observed pond treatment facilities is 41.3 $m^3/m^2/d$), average outlet weir rates exceed design recommendations by approximately 12 times. In fact, at 5 of the 7 treatment facilities examined, outlet weir rates were unacceptably high.

Correlation analyses of design and operating variables with water chemistry variables indicate that the available surface area for sedimentation (area of the settling basin) and overflow rate hold the most meaningful correlations with respect to treatment efficiency. Overflow rate (Vo) is significantly correlated with TSS removal, indicating that the higher the overflow rate, the lower the efficiency of suspended solids removal. Similarly, basin surface area is significantly correlated with TSS removal, indicating that an increase in surface area is concomitant with enhanced removal of TSS. Both of these relationships are logical since solids removal is directly proportional to area, and inversely proportional to overflow rate.

Removal of dissolved phosphorus is enhanced when hydraulic retention time is increased, as is the removal of TSS and TKN. Since retention time is itself immaterial, these relationships likely reflect the overflow rate and surface area relationships discussed above. That is, given a constant hydraulic load, as surface area increases or overflow rate decreases, retention time generally increases as well. The improved performance, however, is more realistically a factor of these latter two variables for the following reason. Retention time is the quotient of the volumetric flow rate divided by basin volume and, therefore, an increase in volume leads to an increased retention time. Increased volume, however, is generally attributed to increased area since, in aquaculture, basin depths are generally relatively constant at 1 to 2 metres. Moreover, TSS removal is highly correlated with area.

Lastly, a significant correlation exists between average fish size and TSS and TKN removal, suggesting that solids removal is facilitated in production units rearing larger fish. The smaller feed and fecal pellets associated with small fish reduce settling velocities and, therefore, make effluent treatment via sedimentation somewhat more difficult. Given similar hydraulic flows and production intensities, a system producing small fish will require a larger settling facility (area) to achieve the same level of performance as an operation raising large fish.

3.0 APPROPRIATE TREATMENT FACILITIES DESIGN AND MANAGEMENT

Due to the high volume of process water associated with intensive salmonid fish culture operations, and the low concentration of particulate and dissolved pollutants, effluent treatment practices are generally limited to primary

treatment technologies; that is, the removal of particulate matter. It is generally agreed that, for efficient and effective removal of solids from fish farm effluents, most existing filtration and screening technologies tend to be impractical from either a functional or economical approach, or both. Notwithstanding that some commercially available treatment units have an application in specific aquaculture operations, sedimentation practices (i.e. gravity separation) tend to be most widely applicable since they require no energy input, are relatively inexpensive to install and operate, require no specialized operational skills, and can be easily incorporated into both new and existing facilities.

When a liquid containing particulate matter is placed into a relatively quiescent state, those particles having a specific gravity greater than that of the liquid begin to settle. Each particle settles at a uniform velocity, which is referred to as the *terminal settling velocity* (Vs).

All continuous flow settling basins are comprised of four zones, and each zone has a specific function (Exhibit 4). The inlet zone serves to uniformly distribute the suspension over the entire cross-section (width and depth) of the basin with minimal turbulence. Sedimentation occurs in the settling zone and, upon removal from the water column, the solids accumulate and remain undisturbed in the sludge zone. The clarified liquid is gently collected over the entire cross-section of the basin at the outlet zone and is discharged.

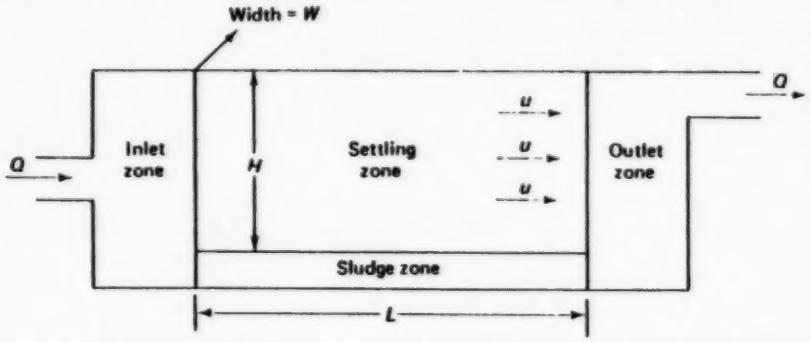


Exhibit 4: Four principle zones of a rectangular continuous flow sedimentation basin.

Under ideal conditions, a particle which starts at the top of the inlet zone and settles to the tank floor at the junction of the outlet zone during its theoretical detention period represents the tank discharge per unit surface area. This is defined as the tank *overflow rate* (Vo), which is simply the solids settling velocity (Vs) presented in different units (i.e. $m^3/m^2/d$ vs. cm/s). Any particle with a settling velocity (Vs) greater than the overflow rate (Vo) will settle out of suspension (see Exhibit 5). Other particles, for which Vs < Vo, will be partially removed, depending upon their vertical position in the tank at the inlet. Consequently, removal is a function of the overflow rate (Vo) and, for a given flow rate, is independent of retention time. Basin surface area is the principal design factor.

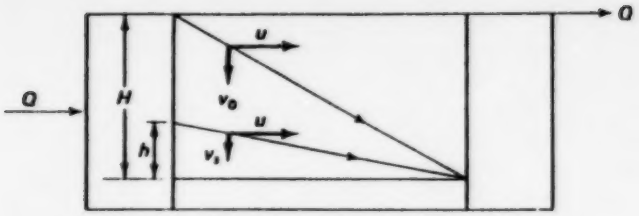


Exhibit 5: Settling paths of discrete particles in a rectangular sedimentation basin.

During the field survey, settling velocity data were collected at 9 smolt production operations. The settling velocity analysis of the effluent suspensions are presented as a cumulative distribution curve (CDC) in Exhibit 3, above. The Y-axis (Cr) represents the fraction of particles (f_o) in the suspension with settling velocities less than the corresponding settling velocity on the X-axis. The fraction of particles removed completely then is equal to 1 - f_o (i.e. those with Vs > Vo) at any given settling velocity (overflow rate). Using mathematical formulas, the fractional removal of those particles with Vs < Vo can also be defined.

The re-suspension of settled particles along the sludge surface by the horizontal flow of water through the basin is termed scour. Scour reduces sedimentation efficiency by stirring up the settled particles and reintroducing them to the water column. For aquacultural waste solids, approximate scour velocities equal 1.6 to 3.8 cm/s. Therefore, a maximum horizontal fluid flow rate of 2 - 4 cm/s is recommended in aquacultural settling basins. Furthermore, since basin depth has only a minimal effect on solids removal efficiency, then basin depth should be maintained as shallow as possible, provided that scour-related problems do not arise.

3.1 Inlet & Outlet Design Considerations

Placing a single pipe at each end of a basin is the simplest design for inlet/outlet structures and, unfortunately, it is perhaps the design most frequently used in aquaculture today. This type of point-source inflow and outflow produces extremely poor flow characteristics for sedimentation. Short-circuiting is severe as the influent stream flows directly through the basin, at high velocity, toward the discharge pipe.

Inlet Design. Submerged weirs, extending across the entire width of a basin, have been found to provide an optimal balance between practicality and flow characteristics for sedimentation. This design utilizes an upward, diverging flow to the weir crest which greatly reduces energy, and the submergence of the weir serves to reduce velocity. To smooth the flow, the weir crest is typically 30 to 60 centimetres wide and has chamfered edges. The top of the weir should be submerged approximately 15% of the basin depth.

Outlet Design. To effectively remove the clarified water from the basin, an outlet weir extending across the width of the basin at the end opposite the inlet is traditionally used. In circular tanks, the outlet weir extends around the outer periphery; the inlet is at the centre. Clarified effluent should be

skimmed off the surface of the basin; hence the overflow design. It is critical that the weir edge be level to assure a uniform discharge rate across the entire weir length.

The weir rate (volume of water discharged per unit length of weir per unit time) governs the length of the outlet weir. Conventional municipal wastewater treatment design standards recommend that weir rates not exceed 186 - 248 m^3/d per metre length of weir (US EPA 1975). In aquacultural operations, where the solids component of the effluent tends to be heavier and more viscous than conventional municipal wastes, a weir rate of 372 $m^3/d/m$ has been recommended for design purposes (Mudrak 1981). Excessive weir rates create an updraft effect near the discharge and, as a result, a portion of the tank volume becomes ineffective for settling since suspended particles entering this section become entrained in the effluent flow.

For tanks which are long relative to their width (as is generally the case in aquaculture), this entrainment effect is confined to an upstream distance equivalent to a few multiples of the basin depth. Since the updraft effect of an outlet weir reduces the effective length of a settling basin, proper design requires that settling basins be lengthened proportionately to compensate for this reduced efficiency. An additional length requirement of 1 to 3 times tank depth is appropriate in most cases. Nevertheless, weir length should be maximized in all applications.

In recent years, the use of circular settling basins has evolved in aquaculture. These basins are typically constructed of galvanized steel silo walls, which are laid into a concrete pad. A single pipe inlet conventionally rises from below ground at the centre of the tank. A distribution baffle, constructed of a perforated steel or plastic barrel, is placed over the inlet pipe, extending from the floor to the surface of the basin. This baffle serves to reduce turbulence and distribute the flow radially across the tank. The outlet from the basin most commonly consists of perforated drainage tile which is moored at the basin surface around the perimeter of the tank. Oversized drainage holes are provided to prevent clogging. Some operators utilize circular basins with a peripheral inlet and a central drain. In the latter case, internal baffles are often used to control the flow of water within the basin. This inward flow approach is comparatively inefficient.

Appropriate Treatment System Design. For New Brunswick smolt operations, treatment facilities designed to operate with an overflow rate of 86.4 $m^3/m^2/d$ (0.100 cm/s) will, on average, discharge only 2.11 mg TSS/L and 0.066 mg TP/L (see example design). When settling area is increased to accommodate a design overflow rate of 25.9 $m^3/m^2/d$, both TSS and TP discharge concentrations will generally be within the Ontario design standards (i.e. < 5 mg TSS/L and < 0.05 mg TP/L; design standards are twice as stringent as compliance standards). Note, however, that large changes in overflow rate do not account for equally large changes in effluent solids and phosphorus concentrations. This is due to the relatively low initial concentrations of these pollutants and the shape of the solids settling and solids removal performance curves. Moreover, these figures can be expected to change as the average size of fish in the system changes. Given that an average fish weighed approximately 27.5 grams at the time of the study, and that a maximum weighted average smolt size is 97 grams, then these discharge figures may be expected to increase by as much as 50% at those times of the production cycle when operating intensities are greatest.

In view of these findings, *design overflow rates* for treatment facilities at New Brunswick smolt production operations which are less than or equal to 86.4 $m^3/m^2/d$ will generally produce acceptable effluent quality. Note that these data assume the use of groundwater or spring water sources having a negligible influent concentration of total phosphorus. In sensitive environments, the mass load of phosphorus and total suspended solids should be used as the basis for effluent concentration limits.

Recommended Design Overflow Rate For
New Brunswick Smolt Production Operations

Culture System	Design Vo ($m^3/m^2/d$)	Settling Rate (cm/s)	Req'd Area (ft^2/IGPM)
N.B. Smolt Tanks	86	0.100	0.82

Since these values represent industry-wide recommendations for average facilities, specific overflow rates may necessitate fine tuning at individual aquaculture facilities to maximize performance. Routine water quality assessment for TSS and TP will be required to permit treatment unit adjustment. In all cases, to achieve optimum performance, it is imperative to compensate for inlet and outlet structure effects by increasing the length of the settling basin as required, over and above the area requirement defined by hydraulic loading and overflow rate.

3.2 Wind Climate Considerations

By providing protection from the wind blowing across the surface of settling ponds, the efficiency of sedimentation will improve since wind-induced currents will not impair the settling process. Windbreaks or shelterbelts can be living or artificial barriers erected for protection against detrimental winds. The degree of wind speed reduction is a function of windbreak height and permeability.

Reductions in wind speed extending from approximately 8 to 60 times the height of the shelterbelt (8-60H) have been reported. Van Eimern et al. (1964) state that, as a rule-of-thumb, the sheltered zone reaches up to about 30H in the lee of the windbreak; however, for wind reduction of 20 percent or more, 20H is more realistic. Several studies have found that below a critical permeability of approximately 30-35%, windbreaks produce a turbulent wake characterized by strong eddies and reversed flow patterns and are thus ineffective. At the opposite extreme, windbreaks having a permeability in excess of 70% provide essentially no wind protection.

Therefore, for New Brunswick operations, which generally utilize relatively large settling ponds, it may be advisable to install appropriate wind protection around the perimeter of the settling facilities. Where multiple ponds are used, placement of wind protection along the berm between successive ponds may also be beneficial. For each production site, the local wind climate records should be consulted to determine the frequency and direction of prevailing winds to facilitate proper placement of shelterbelts.

3.3 Effluent Treatment Design Example

Where possible, a number of small treatment units each designed to clarify a portion of the total process flow is recommended, as opposed to one large treatment unit sized to clarify the entire process flow. Smaller units are easier to manage and clean. It is more realistic to schedule cleaning for a number of smaller basins than one large basin. In each case, the total settling area will be the same, however, cleaning of one small basin as part of a monthly or seasonal routine may be scheduled more readily than can cleaning the entire large basin. Hence, smaller basins are more manageable. Furthermore, the treatment facility should be designed and managed such that individual settling basins can be routinely removed from service for cleaning without disrupting operations or adversely affecting effluent quality; that is, the remaining units should be capable of accommodating the flow from the decommissioned unit.

For the removal of solids from aquacultural effluents, sedimentation basins should be designed with the following factors in mind (Ingersoll et al. 1956):

(1) Overflow rate (Vo), that is, the settling velocity of the smallest particles to be theoretically 100% removed, must be the foundation of basin design. Furthermore, detention periods are, of themselves, immaterial; they result from the design and are <u>not</u> a basis for design.

(2) Turbulence should be compensated for in basin design equations.

(3) Inlet and outlet structures should be specifically engineered in accordance with the characteristics of the basin dimensions and water flow rates.

(4) Basin depth should be as shallow as possible, providing that scour does not interfere with performance.

Consider the following example.

PRODUCTION PARAMETERS		WATER QUALITY PARAMETERS	
Species:	Atlantic Salmon smolts	Total Susp. Solids:	3.98 mg/L
Prod'n Intensity:	76.5 kg/Lps	Total Phosphorus:	0.101 mg/L
Standing Crop:	6973 kg		
Feeding Rate:	1.5% body weight per day		
Flow Rate:	91.2 Lps (1204 IGPM)		

STEP 1. Select the design overflow rate.

Based on findings of the N.B. field survey, Vo = 86.4 $m^3/m^2/d$ (Vs = 0.100 cm/s)

STEP 2. Determine the theoretical solids removal rate.

This is achieved using the data plotted in Exhibit 6, which is derived from Exhibit 3. From Exhibit 6, at Vs = 0.100 cm/s, we see that the expected efficiency is approximately 54%. At existing operations, the design overflow rate can be calculated by dividing the area of the settling basin into the hydraulic flow rate of the basin.

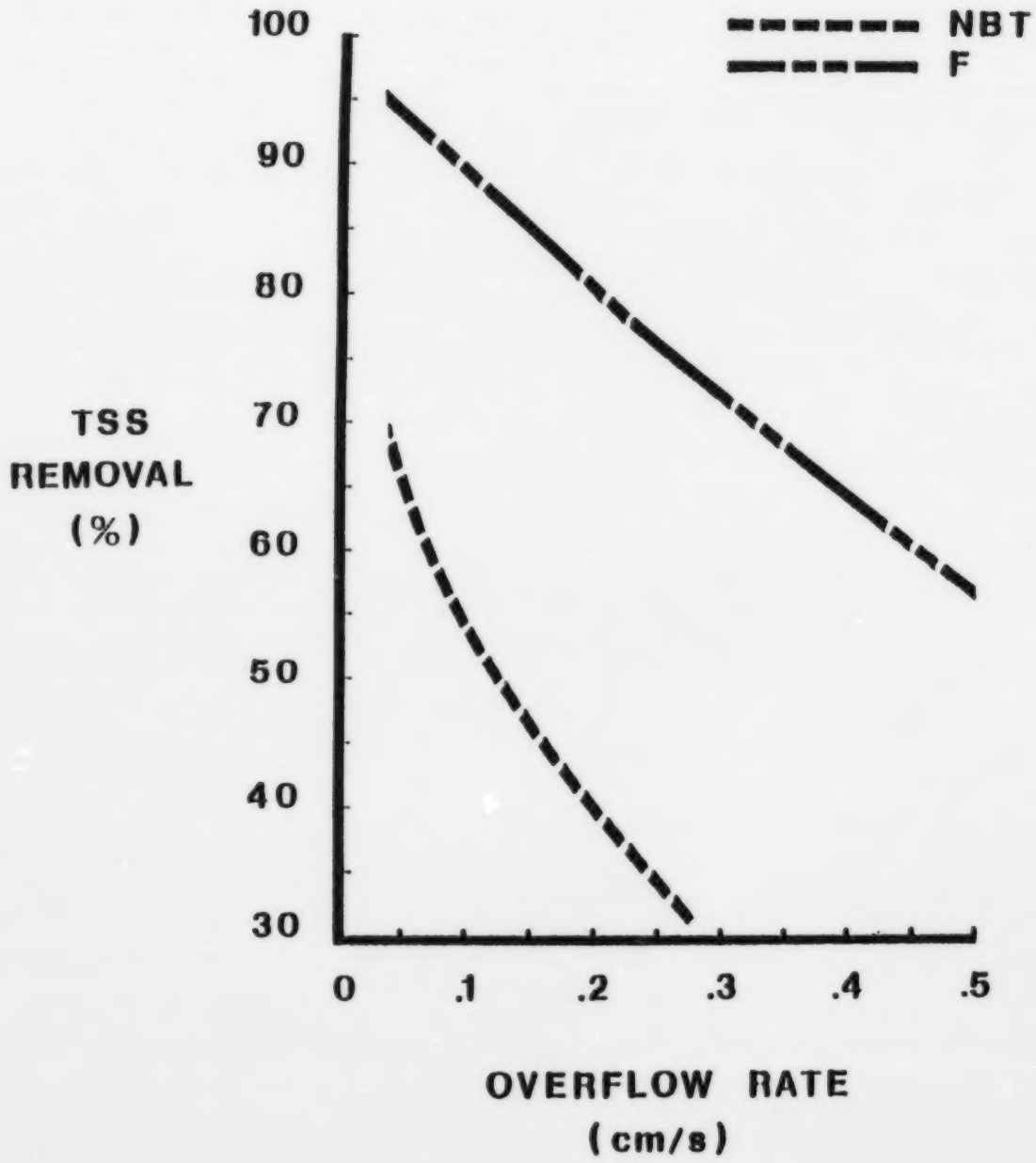


Exhibit 6:
Theoretical average performance curves for efficiency of total suspended solids removal via gravitational settling from the discharged effluent of intensive salmonid smolt culture facilities. NBT = New Brunswick farms; F = Farm 91.

STEP 3. Select appropriate scaling factor.

Using the following table, select a scaling factor to modify the design overflow rate to more accurately reflect the actual level of performance. This scaling compensates for turbulence in the system. We will assume that our treatment unit will be of "good" design and, since our theoretical rate of removal is less than 70%, we will apply a scaling factor of 1.4.

With existing structures, experiential judgement will be required to classify the overall level of basin performance such that the proper scaling factor is selected. For most N.B. operations, scaling factors should be selected from the "very poor" performance category due to the use of inappropriate inlet and outlet structures.

Basin Performance	Removal Efficiency (%)					
	70	75	80	85	90	95
Very Good	1.3	1.5	1.8	2.2	2.7	3.6
Good	1.4	1.7	2.0	2.5	3.2	4.8
Poor	1.7	2.0	2.5	3.2	4.4	6.9
Very Poor	2.3	3.0	4.0	5.9	10	19

Source: Adapted from Fair and Geyer (1958)

STEP 4. Use the scaling factor to convert the *design overflow rate* to the *performance overflow rate* as follows:

Vo = 86.4 x 1.4 = 121.0 $m^3/m^2/d$ (Vs = 0.140 cm/s)

STEP 5. Go back to Exhibit 6 to determine a realistic level of performance.

At Vs = 0.140 cm/s, solids removal efficiency equals approximately 47%.

STEP 6. Project total phosphorus removal using equation:

TP Removal = 0.838 x TSS Removal - 4.679 = 35%

STEP 7. Calculate projected performance.

	Untreated	Removal	Effluent Conc'n
[TSS]	3.98 mg/L	47%	2.11 mg/L
[TP]	0.101 mg/L	35%	0.066 mg/L

STEP 8. Determine if level of treatment is adequate. If not, return to STEP 1 and select a lower overflow rate. If adequate, go to STEP 9.

STEP 9. Calculate required basin dimensions.

Since Vo = Q/A, Then A = Q/Vo
Therefore:
A = 7880 m^3/d / 86.4 m^3/m^2/d = 91.2 m^2
At 2:1 Length:Width ratio, then $2x^2$ = 91.2
x = 6.75 m (22 feet)
Length = 13.5 m (45 feet) Width = 6.75 m (22 feet)

STEP 10. Compensate for inlet turbulence by adding 1 x basin depth = 1.0 m

STEP 11. Calculate outlet weir rate.

OWR = Q/L = 7880 m^3/d / 6.75 m = 1167.4 m^3/m/d
Add appropriate length to settling basin according to chart.

If OWR Equals	Additional basin length requirement
≤ 350 m^3/m/d	1.00 metre
351 - 375	1.25 metres
376 - 400	1.50 metres
401 - 600	2.50 metres
≥ 600 m^3/m/d	3.50 metres

Therefore, add 3.5 metres to settling basin length.

STEP 12. Calculate Overall Dimensions.

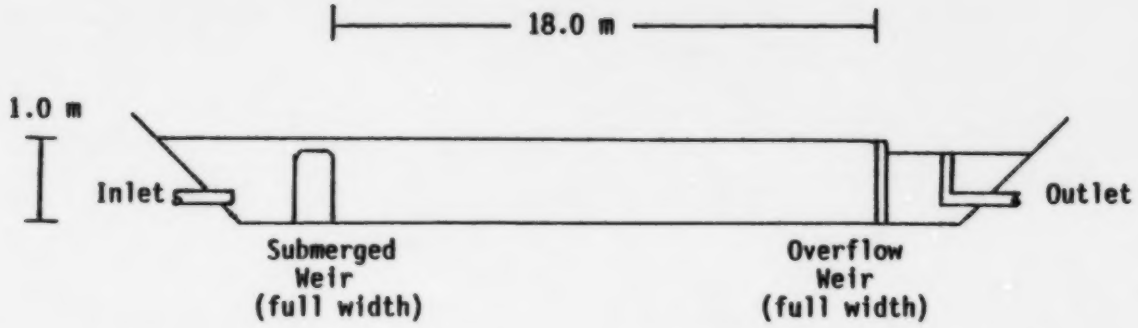
Length = 13.5 m + 1.0 m + 3.5 m = 18.0 m (59 feet)
Width = 6.75 m (22 feet)

STEP 13. Calculate scour effects.

Q = 91.2 Lps Basin Volume = 18.0 m L x 6.75 m W x 1.0 m D
= 121.5 m^3 (121,500 litres)

Hydraulic Retention Time = 121,500 / 91.2 = 1332 seconds
Avg. Horizontal Flow Speed = 1800 cm / 1332 sec = 1.35 cm/s
Critical Scour Velocity = 2 to 4 cm/s
Since Uh < Uc, then scouring will not be a problem.

The following sketch presents a profile of the example basin, including appropriate dimensions.



N.B. Floor may be gently sloped to facilitate draining and cleaning.

3.4 Solids Removal and Disposal

Accumulated manure must be effectively removed to prevent solubilization of particulate nutrients and then be disposed of in an environmentally acceptable manner. Over time, accumulated solids generally become anaerobic at lower layers, resulting in the release of dissolved nutrients. Solubilization of dissolved nutrients (especially phosphorus) is most rapid during the first 2 to 3 days after the solid pellet is discharged into the water, and comparatively little solubilization occurs beyond day 4 (Zeigler 1988). Consequently, unless the solids had been vacuumed from the settling basins and production facilities within 2 to 3 days prior to site visits, the data collected during this investigation represent steady-state concentrations of dissolved and total phosphorus. As such, so long as effluent compliance criteria are achieved in treated wastewaters, the frequency of solids removal from settling facilities remains somewhat flexible.

In large settling basins, such as those employed in the New Brunswick smolt industry, frequent cleaning is not practical. In these cases, the temporary withdrawl of individual ponds from on-line settling will be most appropriate. During this time, all flow to the basin is diverted to the other settling units and the settled manure in the off-line basin can be pumped into transportation tanks or directly onto agricultural land (see *Solids Disposal* below).

Solids Disposal. There is a Chinese philosophy which states: "substances that by others may be considered wastes are only resources out of place." Such is the case with settled fish manure, which has properties similar to low grade fertilizer. Consequently, land application of fish manure remains the best solution for disposal. Typically, trout culture manure contains approximately 1.5% to 5% nitrogen, 1.5% to 3% phosphorus, 0.2% to 0.7% potassium, and 25% organic carbon on a dry weight basis. The pH tends to be slightly acidic.

Since the manure is highly liquid (generally less than 5% solids), it can be spread directly onto agricultural land using liquid manure spreaders and/or irrigation pumps. Where agricultural land is not adjacent to the culture facility, the manure will need to be transported to acceptable, near-by sites. Naturally, this solution is only feasible during the agricultural growing season.

Throughout the winter months, it is necessary to store the collected manure in a suitable holding facility.

The concentration of nitrogen in settled trout manure is the limiting factor governing land application rates. Pennsylvania experience has shown that, in general, manure can be safely applied over land. For mixed grass crops having a nitrogen uptake capacity of 224 kg/ha (200 lbs/Ac), manure application rates should approximate 120 m^3 per hectare (10,600 Imp. gal/Ac), assuming a 5% solids concentration.

3.5 Modification of Existing Effluent Treatment Structures

Currently, most effluent treatment structures at N.B. smolt operations consist of earthen ponds with point-source inlet and outlet structures. Furthermore, most ponds have sufficient area for settling. The major shortcomings of these structures lies in the inlet and outlet design and the earthen structure, which is difficult to clean. Consequently, in most cases, the existing structure can be maintained; however, modifications are required for improved performance. The following factors should be considered.

1) The basin(s) should be lined with concrete, vinyl (Hypalon), asphalt, or hard clay to facilitate draining and cleaning. A gently sloping floor will enhance sludge removal. Economic analyses have indicated that upgrading of earthern ponds by incorporating concrete liners adds $0.05 to the annual production cost on a per-smolt basis.

2) Full-width, submerged, wide-top inlet weirs should be installed in each pond. Concrete is most appropriate. In most cases, the existing inlet piping can remain provided that the weir is installed downstream from the piping.

3) Full-width overflow discharge weirs should also be installed. These structures should be used to control the depth of water in the basin(s) to ensure an overflow action. Once again, concrete structures are recommended and the existing outlet pipes can be maintained provided they are downstream from the weir.

4) To ensure that the surface area is sufficient for the desired level of treatment, the design Steps presented in Section 3.3 should be followed. In determining the necessary area, be certain to add the appropriate length increments to account for inlet turbulence and outlet entrainment effects.

5) To facilitate the removal of accumulated solids, a minimum of two (2) settling basins should be used. While one is being cleaned, all process water can continue to flow through the second unit. In some applications, the use of more than two ponds may further simplify effluent management procedures.

4.0 SUMMARY

While feed presents the source of the pollution problem, specific feed-related factors (i.e. feed brand and type, and feeding method) were not found to impact upon the quality of effluent. While this may not be entirely plausible,

it does suggest that feed-related factors are subordinate to the polluting influence of facility design and culture management practice.

Management strategies must address the issue of fish farms as sources of aquatic pollution on four principal fronts: feed and feeding practices, rearing unit design, solids settling unit design, and solids removal and disposal. All four of these factors are necessarily inter-related. A chain is only as strong as its weakest link and, therefore, pollution must be challenged on all fronts if abatement is to be effective.

4.1 Feed and Feeding Practices

Nearly every major feed manufacturer is conducting research focused upon the development of commercial feeds which have reduced phosphorus content and higher digestibility. Nevertheless, the fish culturist can reduce the pollution impact of feeds through the use of wise feeding practices. Moreover, such practices often produce a financial benefit as well. Rough handling and improper storage of feeds promotes pellet erosion, resulting in an increased level of fines which cannot be utilized by the fish. Proper storage and handling, therefore, can reduce the pollution impact of feeds and result in less feed wastage. Prior to adding feeds to feed hoppers or troughs, screening the pellets will remove the fines, thus preventing their addition to the water; and some manufacturers offer credit for returned fines. Feeding practices can also be managed to reduce pollution and improve fish production. A carefully monitored feeding program will enable the fish culturist to select the optimum pellet size for the size of fish in the facility. Feeding of oversized and/or undersized pellets promotes waste, inefficiency due to poorer feed conversion, and pollution.

4.2 Rearing Unit Design

In all culture facilities, tank design should facilitate the rapid and gentle removal of waste feed and particulate fecal matter from the water column. The longer these materials remain in suspension, the more they are subject to agitation and, consequently, the smaller they become. These smaller particles are then more difficult to remove from suspension and require substantially larger treatment units to achieve the desired level of efficacy. Additionally, leaching of soluble nutrients is enhanced as particle size decreases.

4.3 Solids Settling Unit Design & Waste Disposal

For most commercial-scale intensive salmonid aquaculture operations, solids removal via gravity settling remains the best available technology. Moreover, since total phosphorus concentration and removal is significantly correlated with total suspended solids concentration and removal, gravity settling is also recommended for reduction of effluent concentrations of phosphorus. Specific phosphorus removal technologies (i.e. addition of metal-salts, chemical polymers, and/or lime to promote phosphorus precipitation; biological uptake into cell tissue) are not warranted in aquaculture due to the dilute nature of the wastewater stream and the relative expense of these processes. Treatment units should be designed, and the solid wastes disposed of, according to those parameters presented in Section 3.

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APPENDIX I

Water Quality Data from Participating Fish Farms

FARM	GROUP	INFLUENT (SOURCE)			PRODUCTION EFFLUENT			NET PROD'N EFFLUENT			FARM EFFLUENT			NET FARM EFFLUENT		
		[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]
83	4	0.00	0.010	0.040	3.20	0.135	0.150	3.20	0.125	0.110	2.40	0.084	0.150	2.40	0.074	0.110
84	4	0.00	0.110	0.100	9.80	0.406	0.150	9.80	0.296	0.050	1.20	0.197	0.150	1.20	0.087	0.050
85	4	1.10	0.023	0.020	1.40	0.046	0.045	0.30	0.023	0.025	1.00	0.048	0.090	-0.10	0.025	0.070
86	4	0.71	0.004	0.060	2.25	0.119	0.105	1.54	0.115	0.045	2.20	0.081	0.110	1.49	0.077	0.050
87	4	0.00	0.010	0.070	0.06	0.028	0.050	0.06	0.018	-0.020	0.00	0.021	0.030	0.00	0.011	-0.040
88	4	NA	0.012	0.020	2.38	0.072	0.040	NA	0.060	0.020	1.20	0.110	0.045	NA	0.098	0.025
89	4	NA	0.026	0.040	0.69	0.101	0.065	NA	0.075	0.025	0.38	0.065	0.030	NA	0.039	-0.010
90	4	0.63	0.042	0.010	1.05	0.108	0.053	0.42	0.066	0.043	1.88	0.108	0.060	1.25	0.066	0.050
91	4	0.38	0.006	0.010	0.54	0.048	0.033	0.16	0.042	0.023	0.25	0.055	0.040	-0.13	0.049	0.030
92	4	0.38	0.006	0.010	1.69	0.039	0.020	1.31	0.033	0.010	NA	NA	NA	NA	NA	NA
93	4	0.75	0.020	0.010	3.63	0.232	0.115	2.88	0.212	0.105	1.63	0.209	0.100	0.88	0.189	0.090
MEAN	4	N.B. Circular Tanks			2.43	0.121	0.075	1.79	0.097	0.040	1.10	0.089	0.073	0.64	0.065	0.039

Effluent Treatment Facilities Data

FARM #	TYPE	AREA	FLOW	Vo	INLET	OUTLET	HRT	DEPTH	SLOPE	INTERC	SIZE	TSS	TKN	TP	DP
86	3	445.9	17478	39.2	0.20	25966.4	33.60	0.91	0.4108	0.3821	13	0.978	1.074	0.681	1.048
84	3	278.7	2291	8.2	0.08	1595.0	160.20	0.91	0.1641	0.1082	35	0.226	0.713	0.715	1.000
90	3	1800.0	74304	41.3	0.45	4157.0	34.90	1.00	0.5593	0.7640	14	2.136	0.918	0.831	1.200
83	3	2000.0	10224	5.1	0.29	889.8	422.50	1.50	0.3824	0.4420	12	0.075	0.894	0.622	1.000
93	3	144.0	1702	11.8	0.16	1861.3	222.90	1.83	0.3212	-0.3128	29	0.450	0.958	0.901	0.870
88	3	8640.0	48567	5.6	1.04	2377.5	384.30	1.50	0.3191	0.3335	61	NA	0.996	1.531	1.125
91	3	860.4	10768	12.5	5.85	560.8	140.30	1.22	0.8801	0.4122	56	0.800	0.980	1.196	1.143
MEAN		2024.1	23619	17.7	1.15	5344.0	199.81	1.27	0.4339	0.3042	31	0.778	0.933	0.925	1.055
MIN		144.0	1702	5.1	0.08	560.8	33.60	0.91	0.1641	-0.3128	12	0.075	0.713	0.622	0.870
MAX		8640.0	74304	41.3	5.85	25966.4	422.50	1.83	0.8801	0.7640	61	2.136	1.074	1.531	1.200
S.D.		2783.8	25380	14.5	1.94	8488.6	143.47	0.33	0.2127	0.3089	19	0.682	0.105	0.304	0.103